Swimming Behavior of Individual Zooplankters During Night-time Foraging

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LONG-TERM GOALS

The long-term goal of this research is to learn in what ways and to what extent the individual behavior of zooplankters can affect overall zooplankton population distributions.

OBJECTIVES

The objectives of this research are two-fold: 1) to learn about euphausiid foraging strategies by observing the swimming behavior of large numbers of undisturbed individuals in the photic zone at different times of night, and 2) to learn how euphausiids partition energy between the vertical and horizontal components of motion at different times of night, particularly during vertical migration.

APPROACH

McGehee and Jaffe (1996) measured the three-dimensional tracks of over 300 individual plankters from a one minute long sequence of 3-D images collected with the three-dimensional acoustical imaging system FishTV (FTV) off the coast of California in March, 1993. The data were exciting because they showed evidence of swimming behavior related to area-restricted searching, an optimum foraging behavior for animals in a patchy food environment. However, the tracks were measured by hand, a laborious task indeed. In July 1994 Genin and Jaffe collected a much larger FTV data set in the Red Sea. Part of the data were collected during a three night moored deployment of the instrument at a depth of 27 m in the Gulf of Aqaba, approximately 1.2 km from shore, in water 280 m deep. The transducer had a large vane attached, intended to keep it aimed up-current, so that ensonified animals

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would be undisturbed by the hardware. The volume of water ensonified was approximately 5 m^3. The measurements were supplemented by simultaneous flow measurements using an S4 current meter. Two BONGO net tows made during the experiment indicated that euphausiids (*Euphausia diamedae*, *E. sanzoi*, *Stylocheiron abbreviatum*, and *S. affine*) were well represented in the fauna (10's to 100's per m^3).

The research performed under the present grant examines data from the moored deployment. Our approach has been to develop a method for automatically tracking the animals in this data set and to examine the swimming trajectories thus determined at various times of night, with the goal of learning more about zooplankton night-time foraging, vertical migration behavior, and the partitioning of energy between horizontal and vertical components at different times of night.

WORK COMPLETED

In FY96 we developed a robust algorithm for tracking acoustic targets in the FTV 3-D image sequences. In FY97 we used these methods to track approximately 280,000 individual zooplankters and fish. FY98 has been devoted to analysis of the target tracks. The analysis has been limited to the nights of 27-28 June, and 28-29 June, 1994, with particular emphasis on the first of these two nights, when 8-minute-long image sequences were collected approximately every 30 minutes.

RESULTS

As might be expected, the number of acoustic targets observed increased dramatically after sundown, and decreased again after first light in the morning. The acoustic target strengths were measured, and the maximum target strength for each target was determined. This may be used as a very approximate measure of the length of the animal, provided it is a euphausiid, using a distorted wave Born approximation (DWBA) scattering model (McGehee et al, in the press). Before sundown, the peak in the acoustic target strength distribution was about -88 dB, corresponding at 445 kHz to euphausiids approximately 7 mm in length. This peak was almost certainly an artifact of the tracking algorithm, which did not report targets below -90 dB. The true peak was probably at a much lower target strength. Once it was completely dark, however, the peak shifted to about -78 dB, corresponding to euphausiids about 11 mm in length. This agrees with measurements from the BONGO net samples. In one of the image sequences the whole target strength picture changed, with the peak in the distribution at approximately -50 dB. These animals were clearly fish, for which we do not have good scattering models at 445 kHz.

Our approach to analyzing the data has been to break the motions into a mean component, ascribed to bulk water movement (or possibly vertical migration, in the vertical dimension), and a random component, ascribed to random animal behavior superimposed upon the bulk motion. The mean horizontal component of tracks of the smaller targets (TS < -75 dB) was highly correlated with the horizontal flow measured simultaneously by an S4 current meter. These targets also exhibited strong mean vertical motions throughout the night, both up and down, apparently due to internal waves. Because of the strength of the mean vertical water motion, direct measurements of daily vertical migration rates were not possible.

We also discovered in many of the data a 2-second period vertical oscillation that we ascribe to sensor motion. This oscillation limits our ability to examine the vertical component of random behavior in those data. However, in the data where this vertical oscillation was not present, we have been able to

compare the vertical component of the random energy with the random energy devoted to horizontal swimming. Previously (before we discovered the vertical oscillations in the data) we had publicly declared that the animals put substantially more energy into the vertical component of swimming than into the horizontal component, possibly for "hop-and-sink" foraging. We now know that was an artifact of the vertical oscillations in the sensor. It appears now that the random component of zooplankton swimming behavior is isotropic in three dimensions.

Using the mean random speeds, we estimate that the -78 dB targets (euphausiids) swam slower than 2 cm/s on average, whereas the fish swam at about 4 cm/s on average.

IMPACT

In recent years the use and popularity of Individual Based Models (IBMs) in behavioral ecology has grown with the widespread availability of high speed personal computers (e.g., DeAngelis, 1992). These models provide a set of behavioral rules to large collections of computer "animals," turn them loose to move and interact according to these rules, and finally present the resulting distributions of animals for comparison with real-world distributions. Lack of real-world data for most oceanic animals hampers both the establishment of reasonable behavioral rules and comparison of the computer model with real-world observations. This study has produced measurements that can be used for both. We will soon be testing some very simple IBMs against the data.

RELATED PROJECTS

The data used in this project were originally collected by Genin and Jaffe under a grant from the U.S - Israel Binational Science Foundation. The research done under that grant has benefited from the automated tracking methods developed here. Two other projects have also benefited from the methods developed here: an ONR project by Jaffe and Franks entitled "Acoustic-Optic Integration and Visualization of 3-D Oceanic Measurement", and an NSF project by Ohman and Jaffe entitled "Combined Acoustic and Optical Imaging of Crustacean Macrozooplankton".

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